

THE FOSSIL COLLECTOR

BULLETIN No. 72

MAY 2004



An archaic toothed mysticete whale from Victoria, Australia
Scale bar 10 cm.

Published by
THE FOSSIL COLLECTORS' ASSOCIATION OF AUSTRALASIA
ISSN 1037-2997

THE FOSSIL COLLECTOR'S ASSOCIATION OF AUSTRALASIA

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This publication is not deemed to be valid for taxonomic purposes [see article 8b in the *International Code of Zoological Nomenclature* 3rd edition 1985. Eds W. D. Ride *et al*].

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EDITORIAL NOTES

Regrettably Paul Tierney's recovery from his car accident late last year is taking a lot longer than he had hoped. Consequently, as access to his computer is also restricted, I agreed to put this edition together. Since my computer skills (and equipment) are not quite up to Paul's standard, a little bit of my own 'cut & paste' skills, acquired over 15 years of producing *The Fossil Collector*, have not gone amiss, particularly when WORD (of whatever — year it was designed) decides it knows how to set something out better than I do.

I'm also sorry to report that Eric & Lilo Nowak (NSW) wrote off their car and caravan on the way to the Warragul Gemboree at Easter. Luckily they were not hurt in the accident.

We are indebted to Erich Fitzgerald for his article on Cetacea. Because of its importance, it was necessary to print it all in one issue and hold over some 'In The News' items until September.

Finally, I'm sure all of you hope Paul will be back on his feet very soon.

Frank Holmes

DINOSAUR SPECIES FROZEN IN TIME

Fossil hunters in the Antarctic have discovered the remains of dinosaurs from two previously unknown species, including the largest ever found in the frozen continent. The fossils add to a tiny trove of Antarctic material representing just six types of dinosaurs.

The largest of the recently found dinosaurs is a 190 million year old four-legged plant-eater from the Early Jurassic, found on December 7th, 2003, about 3,900 metres up the side of Mt Kirkpatrick near Antarctic's Beardmore glacier, a mere 640 km from the South Pole.

A team, made up of Professor William Hammer of Augustana College in Rock Island, Illinois; Philip Currie, Dinosaur Researcher at Canada's Royal Tyrrell Museum in Drumheller, Alberta; and three other trained excavators, had flown into the area by helicopter to complete the removal of bones of a carnivorous crested theropod dinosaur, *Cryolophosaurus ellioti*, that had been discovered there in 1991. Now solid rock, the site would have been a soft riverbed in the Early Jurassic Period.

While the team busied themselves with the excavation, their New Zealand mountain safety guide, Peter Braddock, scoured the area in a casual search for other fossils, purely by chance coming across an enormous pelvis, complete with an ilium (one of the dinosaur's hip bones), of an unnamed primitive sauropod, far bigger than the corresponding bones of the *Cryolophosaurus* the team had come to excavate. These bones and much of its vertebral column are being shipped back to the U.S.A. for analysis. However, preliminary investigation suggests that the sauropod would have been 1.8 m to 2.1 m tall and 9 m in length. According to Hammer this may be the largest dinosaur ever found in the Antarctic and perhaps the oldest. Even so, compared to later four-legged plant eating sauropods (such as brachiosaurs and *Diplodocus*) the new species is relatively small.

Less than a week later, 3,200 km across the continent on James Ross Island off the coast of the Antarctic Peninsula, another chance discovery of an unnamed dinosaur was made by a team which included Judd Case, Curator of Vertebrate Paleontology at St Mary's College of California in Moraga; and co-worker James Martin from the South Dakota School of Mines & Technology in Rapid City. This second discovery, on what had been the bottom of a shallow Cretaceous ocean 70 million years ago, consisted of the scant remains of a theropod (a group of dinosaurs which include allosaurs, tyrannosaurs & velociraptors) which would have stood 1.8 m to 2.4 m tall.

The team that made the discovery originally set out to test a theory about the migration of extinct animals by looking for marsupial remains on Vega Island, just off the Antarctic Peninsula that extends towards South America. However, bad weather had trapped the team's boat in ice and they were unable to pursue their original goal, stopping off on James Ross Island instead.

According to Case, dinosaurs discovered in Antarctica so far, present a kind of "relic fauna", most groups being more commonly associated with earlier times elsewhere in the world. During the Late Cretaceous, Antarctica was still covered with the cycads, palms, and ginkos; plants which in other regions were more typical of the Jurassic Period. This may explain why older dinosaur types persisted in the Antarctic.

Information based on a report by John Pickrell for National Geographic News, March 9th, 2004, and various articles in world newspapers.

THE FOSSIL RECORD OF CETACEANS (MAMMALIA) ON THE AUSTRALIAN CONTINENT

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The mammalian Order Cetacea (whales, dolphins, and porpoises) has a long, but poorly documented fossil record in Australia. This is despite the fact that cetacean fossils have been known from Australia since at least the 1860s. Recent work has highlighted a formerly unknown diversity of late Paleogene and Neogene cetaceans, particularly in the State of Victoria. The Southern Ocean was an area of great importance during the origin and evolution of the two extant suborders of Cetacea (the Mysticeti: baleen-bearing filter-feeders; and the Odontoceti: toothed echolocators). Fossil whales from the Oligocene-Pliocene marine sedimentary basins of Victoria are of global significance, providing fresh insights into cetacean evolution.

Key Words: Australia, Victoria, Cetacea, Paleogene, Neogene, fossil record.

INTRODUCTION TO CETACEA

G.G. Simpson (1945 p. 213) noted that "because of their perfected adaptation to a completely aquatic life, with all its attendant conditions of respiration, circulation, dentition, locomotion, etc., the cetaceans are on the whole the most peculiar and aberrant of mammals". However, recent studies have clarified the phylogeny and ancestry of cetaceans (e.g., Gatesy *et al.* 1999, Gingerich 2002, Nikaido *et al.* 1999, Rose 2001). Cetaceans (whales, dolphins and porpoises) are derived from terrestrial mammals (artiodactyls - even-toed ungulates), and indeed in a strictly cladistic sense *are* artiodactyls, being most closely related to the hippopotamus (see Geisler & Uhen 2003 and references therein).

In completing the transition from land to an aquatic existence, the cetaceans have evolved a highly modified skeleton, behavioural characteristics, physiology and ecology. Their numerous morphological attributes are highly derived, relative to terrestrial mammals, all correlating with feeding, reproducing, communicating, breathing and locomotion in the aquatic medium. The size range of extant cetaceans extends from under two meters to more than 25 meters in length, and

includes the largest animals, indeed perhaps the largest organisms ever to have existed on Earth.

In the two extant suborders of Cetacea, Mysticeti and Odontoceti, there are 81 living species in 14 families. Both mysticetes and odontocetes have an undoubted fossil record that dates back to the Early Oligocene, some 30-34 million years ago (Ma) (Fordyce & Barnes 1994, Fordyce & Muizon 2001). The family-level diversity of cetaceans has remained relatively constant since the Late Pliocene, with a maximum known diversity of about 16 families in the Late Miocene (Fordyce & Muizon 2001). The subsequent decline in this diversity may be due to global cooling with the onset of extended glacial periods and sea level fall, as well as increased competition for resources from pinnipeds (sea lions, walruses & seals) and penguins. Another interesting trend is the decrease in abundance of genera with novel anatomy since the Pliocene. The most abundant extant species belong to only a few genera and families, eg. Delphinidae, Balaenopteridae and Ziphiidae.

The following review is based on a more detailed essay in preparation by the author and Dr R.K. Bearlin.

Archaeoceti ('Ancient Whales')

The cetacean suborder Archaeoceti includes archaic whales, which due to their lack of derived features normally associated with mysticetes and odontocetes, cannot be assigned to one of the two extant suborders of Cetacea. Because Archaeoceti is not diagnosed on the basis of shared derived characters, this suborder is paraphyletic. Archaeocetes, as such, therefore consist of a grouping of fossil whales of a generally 'primitive' grade of evolution. It is important to note that some of the more advanced archaeocetes, at least, share a common ancestry with Mysticeti and Odontoceti, and some may be directly ancestral to the modern cetaceans.

The Archaeoceti have a stratigraphic distribution spanning the Early Eocene to perhaps as late as the mid-Oligocene. There are currently five recognised families of archaeocetes: Pakicetidae, Ambulocetidae, Remingtonocetidae, Protocetidae, and Basilosauridae (see Thewissen 1998, and Thewissen & Williams 2002, for excellent reviews). The Pakicetidae are the oldest known cetaceans (Early Eocene, 50-53 Ma), and probably spent most of their time on land (Thewissen *et al.* 2001, Thewissen & Williams 2002). The ambulocetids, remingtonocetids, and

protocetids, represent a diverse array of Eocene cetaceans, which successively display more advanced aquatic adaptations. It must be stressed that these families were not a linear ancestor-descendant line of evolution. They were, instead, representative clades of an Eocene adaptive radiation of bizarre archaeocetes.

The Basilosauridae includes the subfamilies Dorudontinae and Basilosaurinae (Uhen 1998, 2002). As well as the type genera of these subfamilies, *Dorudon* and *Basilosaurus*, several other taxa are known. The Basilosauridae are known from Middle-Late Eocene deposits across the globe, and more controversially, from the earliest Late Oligocene deposits in the Southern Hemisphere. They are particularly significant in cetacean evolution as they include either the presumed ancestors or the sister group of the mysticetes and odontocetes.

No *unequivocal* archaeocetes, and for that matter Eocene cetaceans, have yet been discovered in Australia. This fact seems, at first, very odd, considering that Mid-Late Eocene basilosaurids have been recorded from New Zealand (see Fordyce 1991a). Why not in Australia? This problem is discussed towards the end of this article.

Literature on the Archaeoceti, and the origins of whales, has grown almost exponentially in the last two decades (Thewissen 1998, Zimmer 1998, Ellis 2001, Prothero & Schoch 2002, Thewissen & Williams 2002, and Martin 2004, among others). Many of these authors cite archaic hoofed predators, the Mesonychia, as the likely ancestors of cetaceans. Evidence from palaeontology, comparative anatomy, and molecular biology, quite firmly identify the Artiodactyla (even-toed ungulates), and more specifically the Hippopotamidae, as the sister-group to Cetacea (see Geisler and Uhen 2003, for an up-to-date review of the evidence).

Mysticeti ('Baleen Whales')

The oldest undoubted mysticetes are from the latest Eocene of the Antarctic Peninsula (Mitchell 1989, Fordyce 2003). These earliest mysticetes possessed relatively large, well-developed teeth, not unlike those of basilosaurid archaeocetes. However, the earliest baleen-bearing mysticetes are from the Early Oligocene of New Zealand (Fordyce 1980). During the Oligocene there was a radiation of both archaic toothed and primitive baleen-bearing forms.

Mysticetes include the Balaenopteridae (e.g., Blue, Minke and

Humpback Whales), Balaenidae (Right and Bowhead Whales), Neobalaenidae (Pygmy Right Whale), and the Eschrichtiidae (Grey Whale). Despite the apparent diversity of extant forms (four recognised families), most species are within one genus: *Balaenoptera*. The right whales (Balaenidae), have a fossil record extending back to the early Late Oligocene (~28 Ma) of New Zealand (Fordyce 2002a), this family, therefore, being one of the most ancient living cetacean clades.

Filter-feeding is a definitive feature of all extant mysticete whales, along with the intrinsically associated possession of baleen (see Pivorunas 1979, for detailed discussion). Baleen is made up of the protein keratin, and grows in sheets from the palatal region of the upper jaws. Major evolutionary trends seen in the Mysticeti include: loss of teeth in adults, development of relatively large to very large body size, large skulls relative to body size, shortening of the intertemporal region as rostral bones and the supraoccipital approach one another dorsally, and shortening of the neck (seen in most cetaceans).

Odontoceti ('toothed whales')

The Odontoceti are the most abundant and widespread of the extant Cetacea, and are furthermore among the most recognisable marine mammals, including such species as the bottlenose dolphin (*Tursiops truncatus*), and the orca (*Orcinus orca*). Although the odontocetes are often referred to as the 'toothed' whales, this name is somewhat misleading if applied in a phylogenetic sense, as many cetaceans outside of Odontoceti possessed teeth. Therefore, the name 'toothed' whales should be considered a general name only for Recent Odontoceti.

Odontocetes are characterised by the presence of maxillae that uniquely telescope posteriorly over the orbit to form an expanded bony supraorbital process. In living odontocetes the supraorbital process forms an origin for facial (m. maxillonasolabialis) muscles (Fordyce and Barnes, 1994). The facial muscle complex and nasal apparatus may generate the high-frequency sounds used by living odontocetes to echolocate in navigation and hunting (Fordyce & Muizon 2001). The osteological correlates of the facial muscle complex associated with echolocation are present in the most archaic odontocetes known (Fordyce 1994a, 2002b). It has been suggested that the evolution of echolocation was as crucial to odontocete evolution as filter-feeding was to mysticetes (Fordyce 1992, Fordyce & Barnes 1994). The ability

to echolocate enabled odontocetes to invade deeper marine waters below the photic zone.

To summarise, the major evolutionary trends within Odontoceti include: the expansion and increase in size of the face; shortening of the intertemporal region; elevation of the cranial vertex posterior to the nasals; increased facial asymmetry; enlargement of the basicranial pterygoid sinus fossae; isolation of the ear bones from the skull; and the jaws may become extremely long, narrow, and polydont, or short and blunt, or toothless (Berta & Sumich 1999, Fordyce & Barnes 1994, Fordyce & Muizon 2001, Heyning 1997).

BRIEF HISTORY OF PALAEOCETOLOGY IN AUSTRALIA

Frederick McCoy (1866, 1877) published the first descriptions and figures of Australian fossil cetaceans, beginning the study of a group

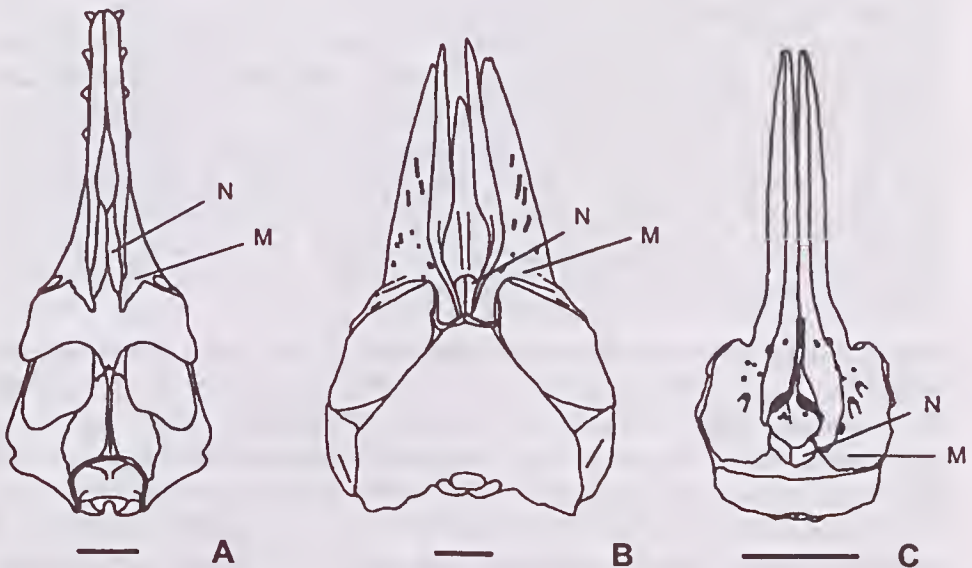


Figure 1. Representative skulls of the three suborders of Cetacea in dorsal view. (A) *Zygorhiza kochii* (Archaeoceti), Eocene; (B) *Balaenoptera acutorostrata* (Mysticeti), Recent; (C) *Delphinus delphis* (Odontoceti), Recent. Note the relative length and position on the skull of the nasal (N) and maxilla (M) bones. A, modified from Kellogg (1936); B & C, original illustrations by the author. Scale bars 100 mm.

that has hitherto remained at the extreme fringes of interest in Australian palaeomammalogy. Several workers who were specialists in geology, invertebrate palaeontology, and zoology, contributed relatively competent studies on fossil cetaceans during the first 50 years of the 20th Century (Chapman 1917, 1918; Flynn 1920, 1923, 1932, 1948; Glaessner 1947, Hall 1911, Pritchard 1939, Scott 1913, Scott & Lord 1921). This period of relatively active study was followed by a long period of inactivity in palaeocetology extending until the late 1970s. However, Glaessner (1955) did formally name two new species of Australian fossil cetaceans after 1950. It is somewhat unfortunate that these were the only new species of fossil cetacean described from Australia, post-World War 2. Fordyce (1982a, 1983, 1984, 1988), Pledge (1994) and Pledge & Rothausen (1977) have been the only recent contributors to Australian palaeocetology, the majority of these latter studies being reviews.

Only one Australian, R. K. Bearlin, has hitherto been formally trained as a vertebrate palaeontologist specialising in the study of whales. Bearlin completed a B.Sc. (Hons.) at Monash University, in which he described a new type of squalodontid odontocete from Batesford Quarry (Bearlin 1982), followed by a Ph.D. under R. Ewan Fordyce at the University of Otago, his thesis being based on Neogene mysticetes from Australia and New Zealand (Bearlin 1987). This latter research, which includes the description of several relatively complete and significant specimens, is to be published by Bearlin in the near future, in conjunction with the revision of some systematics by the author.

Australia has yet to yield a rich high-density cetacean fossil record, unlike some sites in southern New Zealand. This fact may also explain the inconsistency of work in Australian palaeocetology, as most discoveries have occurred by accident. Notable pioneers in the organised collection of Australian fossil cetaceans were G. B. Pritchard, F. S. Colliver, and A. Frostick. These workers collected the majority of Torquay Group cetacean fossils currently in the Museum Victoria collection, including *Mammalodon colliveri*. Although conspicuous in outcrop, complete cetacean fossils are relatively rare. High densities of cetacean fossils, such as found in New Zealand 'bone beds', are only well known from the Pacific and Atlantic coasts of North America, and Egypt (Fordyce & Barnes 1994). It is no coincidence that much of our current knowledge of the cetacean fossil record is derived from these regions.

The Jan Juc Formation, and its Point Addis and Waurin Ponds Limestone Members (Late Oligocene), near Torquay, Victoria, have yielded important and relatively complete cetacean skulls (*Mammalodon*) and postcranial skeletons. Preliminary studies indicate that as many as nine cetacean species may be represented, including archaic toothed mysticetes, two species of *Mammalodon*, balaenid and "cetothere" mysticetes, as well as platanistoid and squalodontid odontocetes (Fitzgerald 2003). This fauna is known from nine localities, indicating that the Australian fossil record of cetaceans is richer than previously thought and worthy of extensive future research. Based on current knowledge, fossil cetaceans seem to be broadly distributed across Victoria, however they are locally rare at most sites.

FOSSIL RECORD OF PALEOGENE-NEOGENE WHALES IN AUSTRALIA

Early Oligocene (33.8-28.5 Ma) - Early Oligocene Cetacea are globally rare, with only a few records from the southwest Pacific. This is probably due to there being less fossiliferous on-shore outcrop of Early Oligocene sediments, especially in southern Australia. Perhaps the oldest described Australian fossil cetacean is '*Squalodon*' *gambierensis* from the Gambier Limestone (probably latest Early Oligocene, but perhaps as young as Early Miocene - N. Pledge, pers. comm.) of South Australia (Glaessner 1955). The holotype is a single tooth described by Glaessner as a buccal tooth from the right mandible. It is not clear, based on the available evidence, whether this specimen represents an upper or lower tooth, although it is probably from a relatively caudal position in the tooth row. In his description, Glaessner was quite certain that this isolated tooth represented the genus *Squalodon*, but while the tooth is indeed superficially similar to the cheek teeth of the latter genus, undoubted species of *Squalodon sensu stricto* are only known from the Miocene of the North Atlantic (Fordyce 1991b, Kellogg 1928, Rothausen 1968). It is thus doubtful that '*S.*' *gambierensis* actually represents a species of *Squalodon*, Fordyce (1991b) suggesting that it may be an indeterminate primitive odontocete or mysticete.

Recently, Fordyce (2002c) indicated that '*Squalodon*' *gambierensis* was closely related to an undescribed Late Oligocene dorudontine basilosaurid from New Zealand. The author has compared a cast of '*Squalodon*' *gambierensis* (Adelaide University Geology Department No. F15107) with casts of cheek teeth of *Basilosaurus cetoides* and

Table 1. Australian fossil cetacean-bearing lithological units. SA=South Australia, T=Tasmania, V=Victoria. O=Oligocene, M=Miocene, P=Pliocene.

Mannum Formation (SA: O-M)	Black Rock Sandstone (V: M-P)
Morgan Group (SA: M)	Fyansford Formation (V: M)
Loxton Sand (SA: P)	Clifton Formation (V: O)
Gambier Limestone (SA: O-M)	Jemmys Point Formation (V: P)
Pata Limestone (SA: M)	Gippsland Limestone (V: M)
Dry Creek Sands (SA: P)	Maude Formation (V: O-M)
Bookpurnong Formation (SA: P)	?Puebla Formation (V: M)
Buccleuch Formation (SA: O)	Whalers Bluff Formation (V: P)
Namba Formation (SA: O-M)	Grange Burn Formation (V: M-P)
Ettrick Formation (SA: O)	Bochara Limestone Member (V: M)
	Muddy Creek Marl Member (V: M)
Gellibrand Marl (V: O)	Calder River Limestone (V: O)
Port Campbell Limestone (V: M)	
Point Addis Limestone (V: O)	Cameron Inlet Formation (T: P)
Jan Juc Marl (V: O)	Fossil Bluff Sandstone (T: ?O-M)
Batesford Limestone (V: M)	

Kellogg's (1936) figures of basilosaurid teeth and concurs with the probability that '*S.*' *gambierensis* represents a mid-late Oligocene archaeocete. The spacing and orientation of the denticles, the long median groove on the basal lingual face of the crown, and the two widely spaced and separate roots of '*S.*' *gambierensis*, are very similar to corresponding features in the much larger cheek teeth of *Basilosaurus cetoides*.

Neville Pledge (1994) described an isolated anterior cheek tooth from the Oligocene of South Australia. This specimen was derived from Fred's Landing, three kilometres downstream from Tailem Bend, on the east bank of the River Murray. The age of the sediments was determined by Pledge (1994) as Early Oligocene, the stratigraphic horizon representing the upper part of the Buccleuch Formation of the Murray Basin. The specimen represents a worn heterodont tooth with two incomplete roots. Pending the discovery of more complete material, the Fred's Landing tooth represents an interesting Early Oligocene record from Australia, and should be considered *Cetacea incertae sedis*.

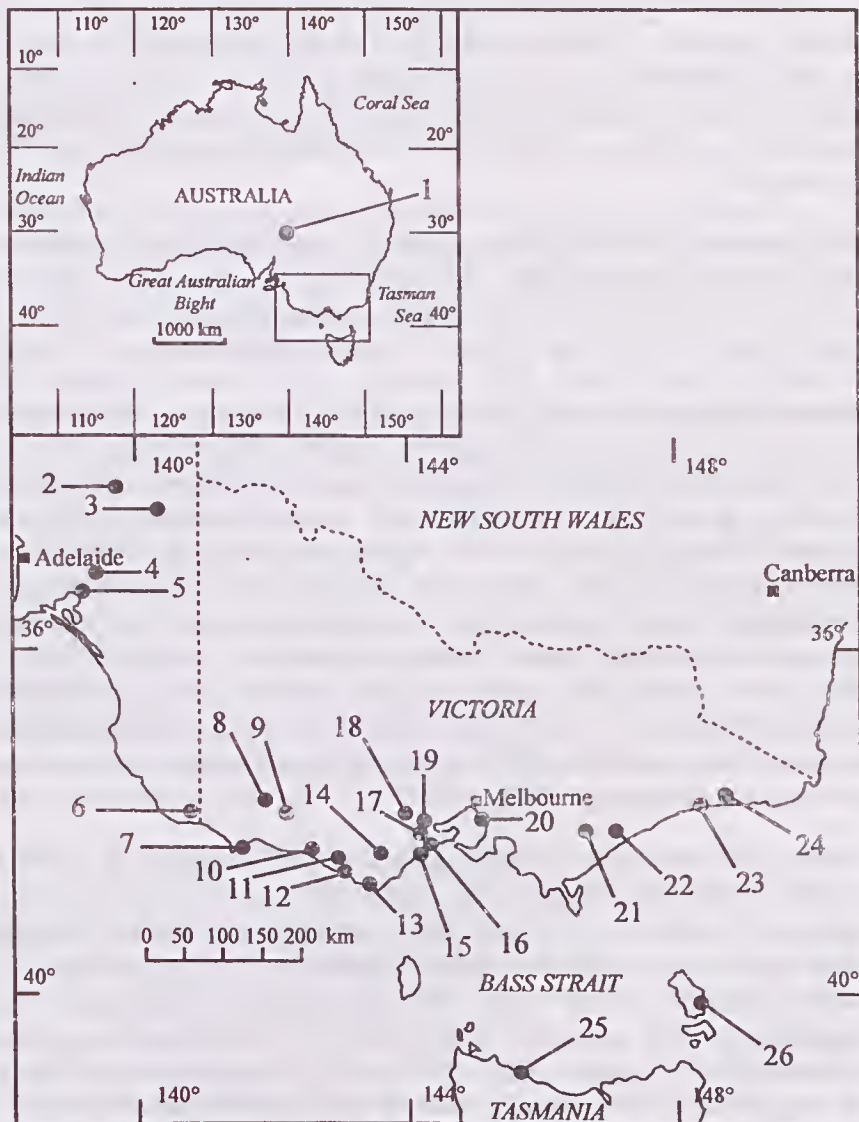


Figure 2. Geographic distribution of the major fossil cetacean-bearing locations in Australia. 1, Lake Frome; 2, Murbko; 3, Loxton; 4, Tailm Bend; 5, Wellington; 6, Mt Gambier; 7, Portland; 8, Grange Burn/Muddy Creek, Hamilton; 9, Spring Creek, Minhamite; 10, Allansford; 11, Timboon; 12, Gibson's Steps; 13, Castle Cove; 14, Kawarren; 15, Aireys Inlet; 16, Coastline between Torquay and Point Addis; 17, Waurm Ponds; 18, Leigh River, Shelford; 19, Batesford; 20, Beaumaris; 21, Rosedale; 22, Longford; 23, Lakes Entrance/Lake Tyers; 24, Newmerella; 25, Fossil Bluff; 26, Cameron Inlet.

An undescribed mysticete skull from an Early Oligocene locality 40 km south of Adelaide, South Australia is in the collection of the South Australian Museum. It consists only of the cranium (it lacks the rostrum, mandibles, and teeth), shows affinities with the basal aetiocetid *Chonecetus* (N. Pledge, pers. comm.).

Late Oligocene (28.5-23.9 Ma) - There is a dramatic global increase in fossil cetacean abundance and diversity in the Late Oligocene, however, this phenomenon is almost certainly due to preservation bias, as discussed in numerous works (Cozzuol 1996; Fordyce 1980, 1982, 1985, 1989a, 1991b, 1992, 2003; Kellogg 1928, Uhen & Pyenson 2002, Whitmore & Sanders 1977). Low diversity of cetaceans in the Early Oligocene may be due to erosion of marginal marine rocks of this age. The global erosion of Early Oligocene marine sediments was probably initiated by a large drop in sea level at the beginning of the Late Oligocene (Fordyce 2003, Uhen & Pyenson 2002). It is noteworthy that most new specimens of Oligocene odontocetes and mysticetes are incompletely prepared and largely unpublished, apart from citations of specimens in abstract form (Fitzgerald 2003, Fordyce 2003, R. D. Fordyce, pers. comm.; M. D. Uhen, pers. comm.). This contrasts with Eocene cetaceans, of which the majority of recognised species have been described. Most of these later Oligocene cetacean taxa are in need of review (Fordyce 1992).

The transition from the Early Oligocene (Rupelian) to the Late Oligocene (Chattian) represents a pivotal time in the evolution of cetaceans. At this time there was probably continuing ecological partitioning amongst early toothed mysticetes (Fordyce 1992). As previously mentioned, a large sea-level change occurred, initially decreasing the total area of marginal marine environments worldwide. Significantly, the Chattian sees the origins and diversification of two other major clades of marine mammals, the Desmostylia and the Pinnipedia (Berta & Sumich 1999). Fordyce (1992) suggested that by end of the Oligocene, the radiation of cetaceans of modern aspect was established, and marine mammal partitioning of the oceans was similar to today.

The Oligocene saw the coexistence of all three cetacean suborders in the world's oceans. From this it can be inferred that trophic partitioning was more complex than in the Eocene and Neogene. Furthermore,

within the Oligocene Autoceta (Mysticeti + Odontoceti) there appears to be a diverse array of feeding ecologies, inferred from cranial and dental functional morphology (see Berta & Sumich 1999, Fordyce 1984, 1989b, 1994, 2002b, 2002c, 2003; Fordyce & Muizon 2001, Ichishima 2002, Mitchell 1989, Okazaki 1987, 2002; Sanders & Barnes 2002).

Australia has yielded a Late Oligocene cetacean fauna that has, in the past, been considered less diverse than that of New Zealand (Fordyce, 1991b). However, unpublished evidence, based on museum collections, now suggests a significantly more diverse Late Oligocene cetacean fauna from southeast Australia.

One of the most unusual records of fossil Cetacea from the southwest Pacific is that of freshwater eurhinodelphinid odontocetes from central Australia. These fragmentary fossils were originally thought to be derived from Middle Miocene fluvial-lacustrine sediments in the Lake Frome region, South Australia. The stratigraphic units these eurhinodelphinids were derived from were the Pinpa and Ericmas faunas of the Namba Formation (Fordyce 1983). These fossils remain the only record of eurhinodelphinids from a freshwater depositional environment. The age of these specimens has recently been considered by Fordyce & Muizon (2001), and Fordyce (2003) to be Late Oligocene, although Alley & Lindsay (1995) have suggested an Oligo-Miocene age for the Namba Formation.

The most complete Oligocene fossil cetacean described from Australia is the putative archaic mysticete *Mammalodon colliveri* (Pritchard, 1939). The holotype specimen, consisting of an almost complete skull, right mandible with six worn teeth, right periotic, right tympanic bulla, one isolated lower cheek tooth, and axis vertebra, was collected from the Jan Juc Formation, near Bird Rock, Torquay, Victoria (Mahoney & Ride 1975, Pritchard 1939, Singleton 1945). The local Janjukian stage has generally been thought to be Late Oligocene/Early Miocene in age (Abele *et al.*, 1988), thus a Late Oligocene age for *M. colliveri* was not considered definite as the specimen was recovered from a stratigraphic horizon near the top of the Jan Juc Formation. However, recent absolute dates for the formation, based on Sr/Sr isotope ratios, and high-resolution biostratigraphy, have shown that the top of the Jan Juc Formation lies at the boundary between the Late Oligocene and Early Miocene (Dickinson 2002, Li *et al.* 1999). In his original report on the discovery of *M. colliveri*, Pritchard (1939, p. 151) noted that the

specimen was "in the cliff face about 12 feet above the level of the beach...barely a hundred yards around the Bird Rock corner". Using $^{87}\text{Sr}/^{86}\text{Sr}$ dates from the Bird Rock-Fisherman's Steps section, it is possible to bracket the age of the horizon *M. colliveri* is derived from, as 25.43-23.9 Ma (Dickinson 2002). *M. colliveri* is thus clearly Late Oligocene in age, and not Early Miocene. Pritchard (1939) and Fordyce (1982, 1984, 1987, 1988) gave preliminary descriptions of particular aspects of the morphology of this species.

Fordyce (1992) noted that other specimens of *Mammalodon* are known from Australia and possibly New Zealand. Several ear bones from the Waurin Ponds Limestone (a unit laterally equivalent to the Jan Juc Formation) and isolated teeth, ear bones, and partial skeletons from the lower Jan Juc Formation, are probably attributable to *Mammalodon* spp. In addition, a second skull from the Jan Juc Formation near Bird Rock, Torquay represents *M. colliveri*, or a species of *Mammalodon* close to *M. colliveri*. Köhler & Fordyce (1997) briefly mentioned this specimen.

Metasqualodon harwoodi, although only based on isolated teeth, has been considered a squalodontid similar to southern hemisphere forms such as *Prosqualodon davidis*, and *P. australis* (Pledge & Rothausen 1977). Sanger (1881) originally described this taxon as *Zeuglodon harwoodi*, but Hall (1911) subsequently transferred this species to the new genus *Metasqualodon*. *M. harwoodi* was derived from the Ettrick Formation (Late Oligocene - Janjucian), near Wellington, on the Murray River, South Australia. The holotype and paratype specimens consist of presumed anterior and posterior cheek teeth, and anterior incisiform teeth. In a detailed review of this species, it was noted that the teeth are "typical squalodontid" (Pledge & Rothausen 1977, p. 288). However, isolated teeth assigned to 'squalodontids' are highly variable, suggesting that no isolated heterodont tooth can *a priori* be considered typical of Squalodontidae. Some isolated cetacean teeth bear morphological features highly characteristic of particular genera and species, eg. *Prosqualodon* spp. (see Flynn 1948). The teeth of *Metasqualodon harwoodi* are not clearly similar to those of other primitive Cetacea, so perhaps this taxon should be assigned to *Autoceta incertae sedis*. It is possible that the denticulate teeth of *Metasqualodon harwoodi* represent a primitive odontocete taxon unrelated to Squalodontidae, or alternatively, a toothed mysticete.

McCoy (1866) described an isolated tooth as the holotype of *Squalodon*

wilkinsoni, and later, Hall (1911) erected a new genus, *Parasqualodon*, for this species. This tooth is probably from the Calder River Limestone (Late Oligocene) near Castle Cove, Aire district, Victoria (Fordyce 1982). Several other isolated teeth of Late Oligocene age have subsequently been referred to this species. These specimens are in the Museum Victoria collection, and one tooth is in the School of Earth Sciences, University of Melbourne. Flynn (1948) recognised the similarity of the holotype tooth of *Parasqualodon* to *Prosqualodon davidis*, but did not suggest that the two were congeneric. Later, Pledge & Rothausen (1977) suggest that *Parasqualodon wilkinsoni* is a species of *Prosqualodon* and Fordyce (1982, 1991) that *Parasqualodon wilkinsoni* is conspecific with *Prosqualodon davidis*. This latter conclusion is followed here; indeed, isolated teeth from the Late Oligocene Jan Juc Formation probably represent *P. davidis*. Even more recently Cozzuol (1996) has suggested that *Prosqualodon davidis* is a junior synonym of *Prosqualodon australis*. Undescribed isolated teeth from the Waurin Ponds Limestone have been referred to *Parasqualodon wilkinsoni*, but they almost certainly do not represent this taxon. These teeth represent a diverse range of cetacean dental morphology, preliminary study suggesting that they belong to *Mammalodon*, cf. ?Platanistoidea, ?Squalodontidae indet., and Cetacea indet.

Several Victorian cetacean fossils are known from the Jan Juc Formation near Bird Rock, Torquay, most being derived from the extensive shore platform horizon; the lower Jan Juc Formation. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios provide a maximum age of 27.38 Ma for this level in the section (Dickinson 2002). Cetacean fossils from the lowermost part of the formation include multiple posterior, and a few anterior, caudal vertebrae. One anterior caudal vertebra, represents a relatively large cetacean, and is phenetically similar to the anterior caudal vertebrae of *Zygorhiza kochii* figured in Kellogg (1936). Other specimens include indeterminate, though relatively small, ribs and periotics. Some conical teeth, associated with a partial skeleton, were identified by Frank C. Whitmore, Junior as probably having delphinoid affinities (personal communication to T. H. Rich). The small size, slender shape, and in one case, very long single root, of these teeth would seem to suggest delphinoid affinities. However, further preparation of the block of marl containing the skeleton has revealed more teeth with two roots, and tooth crowns with distinct denticles; perhaps ruling out delphinoid relationships. These teeth are most similar to those of some primitive toothed mysticetes, such as Aetiocetidae

An incompletely prepared specimen from the Torquay area is the most complete fossil cetacean known from the Australian Paleogene. This specimen was collected from coastal cliff sections of the Jan Juc Formation between Bird Rock and the northeast end of Bells Beach. The combination of characters, so far observable, suggests it is a very primitive toothed mysticete. It shows some similarities with *Mammalodon colliveri* and the North Pacific Aetiocetidae. However, the anatomy of the skull is sufficiently different (more primitive) from these latter taxa to warrant diagnosing this specimen as the sole representative of a new family, genus, and species of toothed Mysticeti.

Early Miocene (23.9-16.4 Ma) - The beginning of the Miocene saw the evolution of cetacean faunas of relatively modern aspect, with an accompanying increase in cetacean diversity through the Miocene (Fordyce & Barnes 1994). The Australian Neogene record of Cetacea is better than that for the Paleogene, however many important specimens remain undescribed.

Australian Early Miocene deposits have yielded some very informative cetacean fossils, several of which have been recorded from near Wynyard, Tasmania. Arguably the most significant Early Miocene cetacean described thus far from the southwest Pacific is *Prosqualodon davidis* (Flynn 1920, 1923, 1932, 1948). Part of the skeleton was exposed in the face of a cliff at Fossil Bluff, near Wynyard, about 7.5 metres above the base of the cliff (Flynn 1923, 1948). In an eroded fallen block from this level the skull, right mandible, and parts of the appendicular skeleton were obtained (Flynn 1948). Unfortunately the holotype skull and other specimens are now lost, Mahoney and Ride (1975) providing a detailed description of the events surrounding the loss of this important specimen. It is likely that further analysis would have provided highly significant information relating to odontocete phylogeny and the systematics of several specimens referred to as 'squalodonts'. The Australian Museum (Sydney); Tasmanian Museum and Art Gallery (Hobart); Natural History Museum (London); Department of Zoology and Comparative Anatomy, University College (London); and the American Museum of Natural History (New York City), all have casts of the skull and mandible (Flynn 1948, Mahoney & Ride 1975).

Other cetaceans have been recorded from the probable Early Miocene of Tasmania. Scott (1913) described fossil cetacean material from Table Cape, near Wynyard, noting that they were probably from nearby Miocene sediments. Elements included parts of the appendicular skeleton, vertebrae and ribs, and vertebral epiphyses. Scott also suggested that these bones represented an immature "ziphioid" whale, however such a determination is probably not possible based on these postcranial remains. Scott and Lord (1921, p. 180) reported "some twenty vertebrae" from "fossil beds" near Wynyard, suggesting they were similar to the vertebrae of *Globicephalus* (pilot whales, family Delphinidae). The same authors also mentioned possible odontocete skull fragments from the area.

Several cetacean fossils have been found in the Early Miocene Batesford Limestone (Longfordian) exposed at Batesford Quarry near Geelong, Victoria. All of this material remains unpublished, however, Bearlin (1982) has described an incomplete large squalodontid skull, and other elements in an unpublished thesis. Bearlin did not name this specimen, but noted that it resembled *Prosqualodon davidis* in many respects, as well as *Phoberodon arctirostris*. Cozzuol (1996) has suggested that *Phoberodon arctirostris* does not belong in Squalodontidae, but may have affinities with *Waipatia maerewhenua*. Notable features of the Batesford squalodontid include the relatively large size of the associated cheek teeth, and the presence of one well preserved periotic. The two cheek teeth preserved with this specimen are very similar to those of an undescribed large squalodontid from the Oligo-Miocene of New Zealand, and *Squalodon bariensis* from the northeast Atlantic (Muizon 1991).

A well-preserved physeterid (sperm whale) mandible is also known from the Early Miocene Batesford Limestone, however this specimen remains unprepared and has not been studied. Skull elements, mandibles, ear bones, vertebrae, and forelimb bones provide evidence for 'cetothere' mysticetes in the Batesford Limestone.

Glaessner (1955) described ?*Aglaocetus* sp., from the Early Miocene of Murbko, South Australia. *Aglaocetus* is a genus of 'cetothere' grade mysticete, previously reported from the Lower Miocene of Patagonia (Kellogg 1928, 1968a). This specimen represents the first 'cetothere' reported from Australia, and includes a relatively complete cranium. Fordyce (1991b) doubted its assignment to *Aglaocetus*, and listed it as

Cetotheriidae, gen. et sp. indet. Earlier Bearlin (1988) had suggested that the specimen described by Glaessner, probably represented a new species, similar to *Parietobalaena*, a genus previously known only from the Early-Middle Miocene of the western North Atlantic, and possibly eastern North Pacific (Bearlin 1988, Kellogg 1968b).

A second 'cetothere', from the Early Miocene of Victoria, was identified by Bearlin (1988) as a new species of *Pelocetus*. This genus was previously known only from the Early-Middle Miocene of the North Atlantic (Kellogg 1965).

In the Gippsland Basin, Early Miocene cetaceans have been found near Longford, Newmeralla, and Rosedale. All these specimens can probably be assigned to the paraphyletic group known as 'cetothere' mysticetes, and include some relatively complete skulls.

Several undescribed Early Miocene cetaceans are also known from South Australia. These include a probable squalodontid from the Mannum Formation, near Blanchetown, a "cetothere" mandible from the Gambier Limestone, near Mount Gambier, and a fragmentary cranium of a relatively large mysticete, probably from the late Early Miocene Morgan Limestone, near Overland Corner (N. Pledge, pers. comm.).

Middle Miocene (16.4-11.2 Ma) - In Victoria, Middle Miocene cetaceans are predominantly found in the Port Campbell Limestone. Two mysticetes are recorded from the Middle Miocene part of this unit; a 'cetothere' grade mysticete that is different from all previously described taxa; and an incomplete skull of a balaenopterid (Bearlin 1988). This latter specimen represents an early global record of the Balaenopteridae, and according to Bealin may be the most primitive balaenopterid documented thus far. The Port Campbell Limestone near Allansford, western Victoria, has yielded a partial mandible with two large teeth, which represents a physeterid odontocete similar to *Scaldicetus*.

Late Miocene (11.2 Ma-5.0 Ma) - Earliest Late Miocene cetaceans are known from Muddy Creek, near Hamilton, Victoria. The most notable specimen being a well preserved periotic (ear bone) of a physeterid, similar to the extant Sperm Whale (*Physeter*).

Most Late Miocene cetaceans have been recovered from the latest Miocene phosphatic nodule horizon, which occurs as a lens of varying thickness across Victoria. This horizon extends from the latest Miocene (Messinian) through to the earliest Pliocene. At some sites the horizon from which fossil cetaceans are derived is undoubtedly latest Miocene, whereas at others, the fossils may be restricted to earliest Pliocene sediments. The Grange Burn Formation (near Hamilton) has been dated as latest Miocene-Early Pliocene (Holdgate & Gallagher 2003), as has the Spring Creek (Minhamite) nodule horizon (Abele *et al.* 1988), while the Black Rock Formation at Beaumaris is considered latest Miocene. In fact, many of the fossils derived from the nodule layer are probably reworked from earlier Miocene deposits, so the cetacean fauna may span a long period of deposition. Despite the varying dates for this nodule horizon, the fauna is considered under the Late Miocene for simplicity.

Specimens from this horizon are often rolled and weathered, fine detail rarely being preserved. However, this horizon has produced the most diverse and abundant cetacean fauna in Australia. Many taxon identifications are based purely on ear bones, although there are some notable exceptions to this preservation bias. Bearlin (1988) reported the almost complete skull and partial skeleton of a new species of *Megaptera* from the latest Miocene-earliest Pliocene of eastern Victoria. This specimen represents the most primitive documented megapterine balaenopterid (humpback whales).

The cetacean fossils from Grange Burn and Beaumaris, Victoria, encompass most of the documented southwest Pacific Neogene Cetacea. The faunas include physeterids (including cf. *Physeter*), putative delphinids, ziphiids (at least three species), at least two species of *Balaenoptera*, cf. *Balaena*, and perhaps as many as four other balaenid species (Bearlin 1988, Fordyce 1982, 1991b). *Scaldicetus lodgei* (Chapman, 1917) from the Mio-Pliocene of Hamilton and *Stenocudmorei* (Chapman, 1917) from the Mio-Pliocene of Beaumaris, were described on the basis of isolated teeth, and are almost certainly *nomina dubia*. From the Grange Burn, Chapman also described partial ziphiid rostra as *Mesoplodon compressus*.

Several cetacean fossils have recently been dredged from the seafloor (2-4 km water depth) on the South Tasman Rise and East Tasman Plateau (Exon *et al.* 1995, N. Kemp, pers. comm.). Sediments in this

area range from Late Oligocene to Pleistocene in age, however, these cetaceans are probably not more than latest Miocene-Late Pliocene in age, based on their morphology and the taxa present. Most consist of worn ziphiid rostra, however at least one relatively complete ziphiid rostrum and partial cranium is present. This specimen is more complete than other ziphiid skulls hitherto recorded from Australia and shows similarities, in the morphology of its cranial vertex and lacrimal, to *Mesoplodon*. Other potentially important specimens recovered from the dredging include a probable mysticete skull, and periotics referred to delphinoids (Exon *et al.* 1995).

Chapman (1918) described *Scaptodon lodderi* as a physeterid, probably derived from the Miocene-Early Pliocene Table Cape sediments of Tasmania. However, this taxon should probably be considered a *nomen nudum*.

Early Pliocene (5.0-3.6 Ma) - Early Pliocene sediments of the Jemmys Point Formation, near Lakes Entrance and Lake Tyers, have yielded fragmentary cetacean remains including a ziphiid rostrum, described by Glaessner (1947) as *Mesoplodon longirostris*, and an unprepared mysticete (?balaenid) cranium.

An almost complete ziphiid rostrum, and part of the skull, have been found in the Early Pliocene Cameron Inlet Formation on Flinders Island, Tasmania. Other specimens from the Pliocene of the Island include balaenopterid, physeterid, and delphinid ear bones (Fordyce 1982, personal observations).

Pledge (1985) described some indeterminate odontocete and mysticete fragments from the Early Pliocene Loxton Sands, near Waikerie, South Australia.

Late Pliocene (3.6-1.8 Ma) - The only possibly Late Pliocene cetacean fauna in Victoria, is known from the 'middle Pliocene' Whalers Bluff Formation of Portland. This fauna, almost entirely represented by isolated ear bones, includes balaenopterids (cf. Balaenopterinae and cf. Megapterinae), balaenids, physeterids, ziphiids, and at least three types of delphinoid (personal observations). A fragmentary balaenid periotic is recorded from the Late Pliocene Dry Creek Sands, near Dry Creek, north of Adelaide, South Australia (Bearlin 1987).

DISCUSSION AND CONCLUSION

Cetaceans probably evolved in the warm, littoral waters of the eastern Tethys Sea in the Early Eocene, and then dispersed west into the Atlantic Ocean and east into the Indo-Pacific region. By the Middle Eocene, basilosaurid taxa (e.g. *Zygorhiza*) had perhaps dispersed southwest from the Atlantic coast of North America, through the open Panama seaway and into the South Pacific. *Zygorhiza*, or a basilosaurid very similar to this genus, existed in the seas around southern New Zealand by the upper Lutetian-middle Bartonian of the Middle Eocene (~ 41 Ma) (Köhler & Fordyce 1997).

The seas around New Zealand appear to have supported diverse communities of cetaceans since at least the late Middle Eocene. Furthermore, other marine tetrapods, such as penguins, also have a history of diversity around New Zealand that extends back to this time (Fordyce, 1991a). Early Oligocene cetaceans from New Zealand include the oldest records of baleen-bearing mysticetes, and the latest Eocene *Llanocetus denticrenatus* from Seymour Island, Antarctic Peninsula, represents the earliest toothed mysticete (Fordyce 1980, 1991b, 2003). These Austral fossils suggest a southern hemisphere origin for Mysticeti and baleen-bearing mysticetes, and by implication, mysticete filter-feeding. Odontocetes have a southern record that extends back to the Late Oligocene, although this group probably diversified in the Early Oligocene (Fordyce 2003). Latest Eocene-earliest Oligocene archaic Odontoceti are known from the northeast Pacific, however, these specimens remain undescribed (Fordyce 2003).

Reasons for the apparent lack of a pre-Oligocene record of Cetacea in Australia are not clear, although a relatively shorter and less consistent history of palaeocetological research in this country is perhaps a contributing factor. Similarly, Early-Late Oligocene cetacean faunas in the seas bordering southern Australia, were almost certainly more diverse than current museum collections would indicate. The presence of apparently endemic and relict Late Oligocene Cetacea (e.g., *Mammalodon colliveri*), probably indicates a longer history of cetacean inhabitation of waters off southern Australia. However, the rather incompletely known Australian Oligocene cetaceans may prohibit any firm conclusions regarding macroevolutionary patterns or palaeozoogeography. Despite this lack of study, some broad statements can be made (based on recent work, and work in progress),

which may point to key objectives for future research in Australian palaeocetology.

It is possible that archaeocetes may have reached northwest Australia before the closure of the eastern Tethys, or perhaps after India docked with Asia, dispersing southeast via the coast of India (Fordyce, 1982). Fordyce suggested that the pre-Late Oligocene Southern Ocean bordering Australia was a narrow seaway that only opened to the west. There may have been limited access to the Late Eocene Australia-Antarctica gulf and seas further east, with only limited shelf areas linking this enclosed ocean to areas of cetacean abundance in eastern Tethys (Fordyce 1982). The Sub-Antarctic convergence and oceanic deep water flow between Tasmania and Antarctica probably did not develop until the earliest Oligocene. Late Eocene deep and shallow waters probably entered the ocean between Australia and Antarctica at the south-western corner of the gulf, circulated anticlockwise around the gulf, exiting northward at the north-western corner (Gammon *et al.* 2003). The Late Eocene marine Bremer, Eucla, and St. Vincent Basin shallow neritic waters, were probably warm temperate to subtropical, with deeper shelf sediments suggesting cooler waters in open marine conditions. Upwelling of warm, nutrient-rich bottom waters occurred along the entire southern Australian Late Eocene shelf margin (Gammon *et al.* 2003). Therefore, it seems that the Late Eocene seas around southern Australia were productive enough to support cetaceans; indeed, Gammon and his colleagues indicated that this environment was similar to the Tethyan seas, where Late Eocene archaeocetes were abundant.

Based on palaeoenvironmental interpretations of these Australian southern margin basins, it is possible to suggest units that may yield Late Eocene cetaceans. The Bremer Basin does not include onshore open marine sediments, and the biosiliceous sponge facies of the palaeo-coastal Pallinup Formation is unlikely to yield cetaceans (Gammon *et al.* 2003). The Eucla Basin Wilson Bluff Limestone includes aerially extensive outer shelf bryozoan chalks (Gammon *et al.* 2003), that may have preserved fossil cetaceans, however, most fossil cetaceans are known from shallow neritic deposits (Fordyce & Barnes 1994). The St. Vincent Basin includes Late Eocene shallow neritic sediments that are perhaps the most likely of the Late Eocene Basin sequences to have preserved cetacean fossils. Penguin fossils are known from the St. Vincent Basin Late Eocene Blanche Point Formation

of South Australia, however no cetaceans have been recorded from this unit (Jenkins 1974).

Perhaps the most plausible explanation for the apparent lesser diversity of Palaeogene cetaceans in Australia, compared to New Zealand, lies in Australia's southern margin not being open to the Pacific Ocean until the Early Oligocene. The Oligocene cetacean faunas of the North Pacific are quite diverse, and it is possible that cetaceans in the Pacific were not able to disperse southwest into the Southern Ocean bordering Australia until the late Early Oligocene, when the Circum-Antarctic Current had become well established. Archaeocetes are known from the Late Eocene southeast Pacific, Antarctica, and New Zealand (Cozzuol 1996, Fordyce 2003) and *Llanocetus* from the latest Eocene of Antarctica, and perhaps the Early Oligocene of New Zealand. Some cetacean taxa had thus begun encircling the Southern Ocean by at least the Late Eocene.

The earliest record of cetacean taxa inhabiting Australian waters and other parts of the Southern Ocean is represented by the Late Oligocene genus *Mammalodon*, although the identification of New Zealand specimens as belonging to this genus is still uncertain (R. E. Fordyce, pers. comm.). It is notable that we see an apparent increase in cetacean diversity and abundance in the Janjukian (Late Oligocene) of Victoria. Near the base of the Jan Juc Formation, close to Torquay (27-25 Ma), the first cetacean fossils from this section are reported. It is from approximately this horizon, upwards through the Early Miocene Puebla Clay to about 20 Ma, that phosphate horizons, often associated with episodes of marine transgression, are recorded. As sea level rises, phosphogenesis is enhanced by a marine environment more favourable to this process. At the same time, nutrient-rich waters are also expelled to the surface as upwelling occurs (Dickinson 2002). Phosphate horizons in the Jan Juc Formation indicate episodes of upwelling and nutrient enrichment in the marine environment, with faunal activity increasing. Dickinson (2002) also reported that the main episode of phosphate precipitation and upwelling, in the Otway and Torquay Basins, occurred between 25 and 20 million years ago. It is within this period that fossil cetaceans become more diverse and abundant in Victorian sediments. It is possible that cetacean inhabitation along the southern margin of Australia was limited, during the earlier Palaeogene, due to an unfavourable marine environment; a possibility raised by Fordyce (1982). Prior to the Late Oligocene, warm water upwelling

taking place in the Australia-Antarctica gulf may not have produced the necessary plankton biomass to support a diverse, permanent, cetacean fauna. The Late Oligocene upwelling in the Torquay Basin could have been derived from cool bottom waters, by this time related to the development of the psychrosphere (cold, descending watermasses that develop around Antarctica and disperse northwards) (Vickers-Rich & Rich, 1993).

By the Miocene, many Austral cetaceans had a circum-polar distribution (e.g., Balaenidae, *Prosqualodon*), and some forms had trans-equatorial, or anti-tropical distributions (eg. Australian 'cetotheres'). The Early Miocene saw a possible reduction in Antarctic ice, global thermal maximum and higher sea level than the Late Oligocene (Fordyce 1989a). The rise in sea level from the latest Late Oligocene through to the Middle Miocene corresponds to a global increase in organic-rich sediments (Parrish & Curtis 1982). Cetaceans diversified through the Middle Miocene, with a global climatic optimum at this time (Gallagher et al. 2001). The Late Miocene appears to represent a period of maximum cetacean diversity (Fordyce & Muizon 2001) which at the family level has not been paralleled since. *Australodelphis mirus*, a bizarre ziphiid-like dolphin from the Early Pliocene of east Antarctica provides insights into the evolution of the post-Miocene Antarctic cetacean fauna (Fordyce et al. 2002). Small Antarctic odontocetes do not live in the same setting at present, as they did in the Pliocene. This suggests that a comparatively recent change in Antarctic cetacean ecology has occurred due to geologic/climatic influences on the marine environment. Ice-dwelling diatoms are absent from the sediments *A. mirus* was derived from, indicating that this dolphin lived in a marine shelfal setting free of significant sea ice (Fordyce et al. 2002).

Novel adaptations are seen in many Late Miocene-Early Pliocene cetaceans, such as *Australodelphis* and the walrus-convergent delphinoid *Odobenocetops peruvianus* (Fordyce et al. 2002, Muizon et al. 2002). The subsequent extinctions or changes to geographic ranges of these cetacean taxa, following the Early Pliocene, indicate that a major change in the marine environment and cetacean ecology has occurred in the last 3-4 million years. This also suggests that cetacean faunas of truly modern aspect only evolved some four million years ago. Further study of Neogene cetaceans in the southwest Pacific is required before this hypothesis can be more broadly corroborated in the southern hemisphere.

The above statements are based to a large extent on an incompletely known record of Paleogene and Neogene fossil cetaceans in the southwest Pacific. It is likely that further investigation and future fossil discoveries will necessitate modifications to our current understanding of cetacean evolution in the southwest Pacific. In order to interpret broader patterns, much work needs to be done in the description, analysis and phylogenetic systematics of Australian fossil Cetacea in particular.

Research carried out in New Zealand points to the continued existence of basilosaurid archaeocetes into the Late Oligocene (R. E. Fordyce, pers. comm.). Other specimens from the Oligocene of Victoria and South Australia, may represent basilosaurids. *Mammalodon colliveri* has no close relatives in the Late Oligocene of the northern hemisphere, and may have been endemic to the southwest Pacific. This cetacean genus is a good example of mosaic evolution in Cetacea. *Mammalodon's* similarity to mysticetes is clear, yet it remains to be proved that it is unquestionably not an archaeocete. The coexistence of archaeocetes, primitive and advanced mysticetes, and varied odontocetes, during the Oligocene of the southwest Pacific, indicates that, under unique circumstances, the evolution of some marine mammal faunas may have taken a slightly different course in the seas around Australasia. Such a unique evolutionary pattern has already been recorded for this region's terrestrial mammals.

ACKNOWLEDGEMENTS

Early versions of this article were read by T.H. Rich and P. Vickers-Rich, whose comments helped improve the quality. The author thanks R.K. Bearlin, T.A. Darragh, R.E. Fordyce, S.J. Gallagher, J. Geisler, N. Kemp, D. Pickering, T.H. Rich, R. Schmidt, J. Stilwell, M.D. Uhen, and M. Wallace for valuable discussions on topics relevant to this study.

D. Bohaska, J. Mead and the National Museum of Natural History (Smithsonian Institution) are thanked for assistance with literature resources. The Fossil Collectors' Association of Australasia is also thanked for inviting this contribution. This work forms part of a Ph.D. project undertaken at Monash University and Museum Victoria, Melbourne, Australia.

REFERENCES

- Abele, C., Gloe, C. S., Hocking, J. B., Holdgate, G., Kenley, P. R., Lawrence, C. R., Ripper, D., Threlfall, W. F. & Bolger, P. F., 1988. Tertiary; pp. 251-350 in J. G. Douglas and J. A. Ferguson (eds.), *Geology of Victoria*. Victorian Division, Geological Society of Australia Incorporated, Melbourne.
- Alley, N. F., & Lindsay, J. M. (compilers), 1995. Tertiary; pp. 151-218 in J. F. Drexel and W. V. Preis (eds.), *The Geology of South Australia. Volume 2, The Phanerozoic*. Bulletin of the Geological Survey of South Australia 54 (2).
- Bearlin, R. K., 1982. A new "shark-toothed dolphin" (Order Cetacea, Family Squalodontidae) from Batesford, Victoria, Australia. B.Sc. (Honours) thesis, Monash University, Clayton, 133 pp.
- Bearlin, R. K., 1987. The morphology and systematics of Neogene Mysticeti from Australia and New Zealand. Ph.D. Thesis, University of Otago, Dunedin, New Zealand, 212 pp.
- Bearlin, R. K., 1988. The morphology and systematics of Neogene Mysticeti from Australia and New Zealand (Abstract of Ph.D. Thesis, University of Otago, Dunedin). *New Zealand Journal of Geology and Geophysics* 31: 257.
- Berta, A., & Sumich, J. L., 1999. *Marine Mammals: Evolutionary Biology*. Academic Press, USA, 494 pp.
- Chapman, F., 1917. New or little-known Victorian fossils in the National Museum. Part XXI-some Tertiary cetacean remains. *Proceedings of the Royal Society of Victoria* 30: 32-43.
- Chapman, F., 1918. On an apparently new type of cetacean tooth from the Tertiary of Tasmania. *Proceedings of the Royal Society of Victoria* 30: 149-152.
- Cozzuol, M. A., 1996. The record of the aquatic mammals in southern South America; pp. 321-342 in G. Arratia (ed.), *Contributions of Southern South America to Vertebrate Paleontology. Münchner Geowissenschaftliche Abhandlungen, Reihe A: Geologie und Paläontologie* 30.
- Dickinson, J. A., 2002. Neogene tectonism and phosphogenesis across the SE Australian margin. Ph.D. thesis, University of Melbourne, Melbourne, 229 pp.
- Ellis, R., 2001. *Aquagenesis: The Origin and Evolution of Life in the Sea*. Viking Penguin, New York, 304 pp.
- Exon, N. F., Marshall, J. F., McCorkle, D. C., Alcock, M., Chaproniere, G. C. H., Connell, R., Dutton, S. J., Elmes, M., Findlay, C., Robertson, L., Rollet, N., Samson, C., Shafik, S. & Whitmore, G. P., 1995. *Tasman Rises* geological sampling cruise of *Rig Seismic*: stratigraphy, tectonic history and palaeoclimate of the offshore Tasmanian region. AGSO Cruise 147 Report. Australian Geological Survey Organisation.
- Fitzgerald, E. M. G., 2003. Oligocene Cetacea (Mammalia) from the southern margin of Australia. *Geological Society of Australia Abstracts* 70: 17.
- Flynn, T. T., 1920. Squalodont remains from the Tertiary strata in Tasmania. *Nature* 106: 406-407.
- Flynn, T. T., 1923. A whale of bygone days. *Australian Museum Magazine* 1: 266-272.
- Flynn, T. T., 1932. A new species of fossil cetacean from Tasmania. *Geological Magazine* 69: 327-329.
- Flynn, T. T., 1948. Description of *Prosqualodon davidi* Flynn, a fossil cetacean from Tasmania. *Transactions of the Zoological Society of London* 26: 153-197.

- Fordyce, R. E., 1980. Whale evolution and Oligocene Southern Ocean environments. *Palaeogeography, Palaeoclimatology, Palaeoecology* 31: 319-336.
- Fordyce, R. E., 1982. A review of Australian fossil Cetacea. *Memoirs of the National Museum Victoria* 43: 43-58.
- Fordyce, R. E., 1983. Rhabdosteld dolphins (Mammalia: Cetacea) from the Middle Miocene, Lake Frome area, South Australia. *Alcheringa* 7: 27-40.
- Fordyce, E., 1984. Evolution and zoogeography of cetaceans in Australia; pp. 929-948 in M. Archer and G. Clayton (eds.), *Vertebrate Zoogeography and Evolution in Australasia*. Hesperian Press, Australia.
- Fordyce, R. E., 1985. The history of whales in the Southern Hemisphere; pp. 79-104 in J. K. Ling and M. M. Bryden (eds.), *Studies in Sea Mammals in South Latitudes*. South Australian Museum, South Australia.
- Fordyce, E., 1987. Beginnings of the baleen whales; pp. 54-56 in S. Hand and M. Archer (eds.), *The Antipodean Ark*. Angus and Robertson Publishers, Australia.
- Fordyce, R. E., 1988. Taxonomic status of Victorian fossil whales assigned to the genus *Cetolites* McCoy, 1879. *Memoirs of the Museum of Victoria* 49: 59-65.
- Fordyce, R. E., 1989a. Origins and evolution of Antarctic marine mammals; pp. 269-281 in J. A. Crame (ed.), *Origins and Evolution of the Antarctic Biota*. *Geological Society Special Publication* 47.
- Fordyce, R. E., 1989b. Problematic Early Oligocene toothed whale (Cetacea, ?Mysticeti) from Waikari, North Canterbury, New Zealand. *New Zealand Journal of Geology and Geophysics* 32: 395-400.
- Fordyce, R. E., 1991a. A new look at the fossil vertebrate record of New Zealand; pp. 1191-1316 in P. Vickers-Rich, J. M. Monaghan, R. F. Baird, and T. H. Rich (eds.), *Vertebrate Palaeontology of Australasia*. Pioneer Design Studio in co-operation with Monash University Publications Committee, Melbourne.
- Fordyce, R. E., 1991b. The Australasian marine vertebrate record and its climatic and geographic implications; pp. 1165-1190 in P. Vickers-Rich, J. M. Monaghan, R. F. Baird, and T. H. Rich (eds.), *Vertebrate Palaeontology of Australasia*. Pioneer Design Studio in co-operation with Monash University Publications Committee, Melbourne.
- Fordyce, R. E., 1992. Cetacean evolution and Eocene/Oligocene environments; pp. 368-381 in D. R. Prothero and W. A. Berggren (eds.), *Eocene-Oligocene Climatic and Biotic Evolution*. Princeton University Press, USA.
- Fordyce, R. E., 1994. *Waipatia maerewhenua*, new genus and new species (Waipatiidae, new family), an archaic Late Oligocene dolphin (Cetacea: Odontoceti: Platanistoidea) from New Zealand; pp. 147-176 in A. Berta and T. Deméré (eds.), *Contributions in Marine Mammal Paleontology Honoring Frank C. Whitmore, Jr. Proceedings of the San Diego Society of Natural History* 29.
- Fordyce, R. E., 2002a. Oligocene origins of skim-feeding right whales: a small archaic balaenid from New Zealand. *Journal of Vertebrate Paleontology* 22 (supplement to no. 3): 54A.
- Fordyce, R. E., 2002b. *Simocetus rayi* (Odontoceti: Simocetidae, new family): a bizarre new archaic Oligocene dolphin from the eastern North Pacific; pp. 185-222 in R. J. Emry (ed.), *Cenozoic Mammals of Land and Sea: Tributes to the Career of Clayton E. Ray*. *Smithsonian Contributions to Paleobiology* 93.
- Fordyce, R. E., 2002c. Oligocene archaeocetes and toothed mysticetes: Cetacea from times of transition; pp. 16-17 in R. E. Fordyce and M. Walker (eds.), *Secondary Adaptation to Life in Water: Abstracts*. *Geological Society of New Zealand Miscellaneous Publication* 114A.

- Fordyce, R. E., 2003. Cetacean evolution and Eocene-Oligocene oceans revisited; pp. 154-170 in D. R. Prothero, L. C. Ivany, and E. A. Nesbitt (eds.), *From Greenhouse to Icehouse: the Marine Eocene-Oligocene Transition*. Columbia University Press, New York.
- Fordyce, R. E. & Barnes, L. G., 1994. The evolutionary history of whales and dolphins. *Annual Review of Earth and Planetary Sciences* 22: 419-455.
- Fordyce, E. & Muizon, C. de, 2001. Evolutionary history of cetaceans: a review; pp. 169-233 in J. M. Mazin and V. de Buffr  nil (eds.), *Secondary Adaptation of Tetrapods to Life in Water*. Verlag Dr. Friedrich Pfeil, M  nchen, Germany.
- Fordyce, R. E., Quilty, P. G. & Daniels, D., 2002. *Australodelphis mirus*, a bizarre new toothless ziphiid-like fossil dolphin (Cetacea: Delphinidae) from the Pliocene of Vestfold Hills, East Antarctica. *Antarctic Science* 14: 37-54.
- Gallagher, S. J., Smith, A. J., Jonasson, K., Wallace, M. W., Holdgate, G. R., Daniels, J. & Taylor, D., 2001. The Miocene palaeoenvironmental and palaeoceanographic evolution of the Gippsland Basin, Southeast Australia: a record of Southern Ocean change. *Palaeogeography, Palaeoclimatology, Palaeoecology* 172: 53-80.
- Gammon, P. R., Bone, Y., Clarke, J. D. A. & James, N. P., 2003. Upper Eocene greenhouse deposits in southern Australia: paleoclimatology and paleoceanography; pp. 107-118 in D. R. Prothero, L. C. Ivany, and E. A. Nesbitt (eds.), *From Greenhouse to Icehouse: the Marine Eocene-Oligocene Transition*. Columbia University Press, New York, USA.
- Gatesy, J., Milinkovitch, M., Waddell, V. & Stanhope, M., 1999. Stability of cladistic relationships between Cetacea and higher-level artiodactyl taxa. *Systematic Biology* 48: 6-20.
- Geisler, J. H. & Uhen, M. D., 2003. Morphological support for a close relationship between hippos and whales. *Journal of Vertebrate Paleontology* 23: 991-996.
- Gingerich, P. D., 2002. Origin and relationships of Cetacea: evidence from the fossil record. *Journal of Vertebrate Paleontology* 22 (supplement to no. 3): 59A.
- Glaessner, M. F., 1947. A fossil beaked whale from Lakes Entrance, Victoria. *Proceedings of the Royal Society of Victoria* 58: 25-34.
- Glaessner, M. F., 1955. Pelagic fossils (*Aturia*, penguins, whales) from the Tertiary of South Australia. *Records of the South Australian Museum* 11: 353-372.
- Hall, T. S., 1911. On the systematic position of the species of *Squalodon* and *Zeuglodon* described from Australia and New Zealand. *Proceedings of the Royal Society of Victoria* 23: 257-265.
- Heyning, J. E., 1997. Sperm whale phylogeny revisited: analysis of the morphological evidence. *Marine Mammal Science* 13: 596-613.
- Holdgate, G. & Gallagher, S. J., 2003. Tertiary: a period of transition to marine basin environments; pp. 289-335 in W. D. Birch (eds.), *Geology of Victoria*. Geological Society of Australia Special Publication 23. Geological Society of Australia (Victoria Division).
- Ichishima, H., 2002. What were archaic mysticetes like? An example of some latest Oligocene to earliest Miocene New Zealand whales; pp. 24-25 in R. E. Fordyce and M. Walker (eds.), *Secondary Adaptation to Life in Water: Abstracts. Geological Society of New Zealand Miscellaneous Publication* 114A.
- Jenkins, R. F., 1974. A new giant penguin from the Eocene of Australia. *Palaeontology* 17: 291-310.
- Kellogg, A. R., 1928. The history of whales-their adaptation to life in the water. *The Quarterly Review of Biology* 3: 29-76, 174-208.

- Kellogg, A. R., 1936. A review of the Archaeoceti. *Carnegie Institution of Washington Publication* 482: 1-366.
- Kellogg, A. R., 1965. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia. Part 1. A new whalebone whale from the Miocene Calvert Formation. *United States National Museum Bulletin* 247: 1-45.
- Kellogg, A. R., 1968a. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia. Part 7. A sharp-nosed cetotheres from the Miocene Calvert. *United States National Museum Bulletin* 247: 163-173.
- Kellogg, A. R., 1968b. Fossil marine mammals from the Miocene Calvert Formation of Maryland and Virginia. Part 8. Supplement to description of *Parietobalaena palmeri*. *United States National Museum Bulletin* 247: 175-197.
- Köhler, R. & Fordyce, R. E., 1997. An archaeocete whale (Cetacea: Archaeoceti) from the Eocene Waihao Greensand, New Zealand. *Journal of Vertebrate Paleontology* 17: 574-583.
- Li, Q., Davies, P. J. & McGowran, B., 1999. Foraminiferal sequence biostratigraphy of the Oligo-Miocene Janjukian strata from Torquay, southeastern Australia. *Australian Journal of Earth Sciences* 46: 261-273.
- Mahoney, J. A. & Ride, W. D. L., 1975. Index to the genera and species of fossil Mammalia described from Australia and New Guinea between 1838 and 1968. *Western Australian Museum Special Publication* 6: 1-250.
- Martin, R. A., 2004. *Missing Links: Evolutionary Concepts and Transitions Through Time*. Jones and Bartlett Publishers, Sudbury, Massachusetts, 303 pp.
- McCoy, F., 1866. *Notes sur la zoologie et la palaeontologie de Victoria, par Frederick M'Coy*. Masterman, Melbourne, 35 pp.
- McCoy, F., 1877. *Prodromus of the Palaeontology of Victoria; or, figures and descriptions of the Victorian organic remains*. Decade 5. Government Printer, Melbourne.
- Mitchell, E. D., 1989. A new cetacean from the Late Eocene La Meseta Formation, Seymour Island, Antarctic Peninsula. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 2219-2235.
- Muizon, C. de, 1991. A new Ziphiidae (Cetacea) from the early Miocene of Washington State (USA) and phylogenetic analysis of the major groups of odontocetes. *Bulletin du Muséum Nationale d'Histoire Naturelle, Paris, 4 Série*, 12C (3-4): 279-326.
- Nikaido, M., Rooney, A. P. & Okada, N., 1999. Phylogenetic relationships among cetartiodactyls based on insertions of short and long interspersed elements: hippopotamuses are the closest extant relatives of whales. *Proceedings of the National Academy of Sciences, USA* 96: 10261-10266.
- Okazaki, Y., 1987. Additional materials of *Metasqualodon symmetricus* (Cetacea: Mammalia) from the Oligocene Ashiya Group, Japan. *Bulletin of the Kitakyushu Museum of Natural History* 7: 133-138.
- Okazaki, Y., 2002. Possible dentition of an archaic baleen whale from the Oligocene Ashiya Group, Japan; pp. 37 in R. E. Fordyce and M. Walker (eds.), *Secondary Adaptation to Life in Water: Abstracts*. Geological Society of New Zealand *Miscellaneous Publication* 114A.
- Parrish, J. T. & Curtis, R. L., 1982. Atmospheric circulation, upwelling, and organic-rich rocks in the Mesozoic and Cenozoic eras. *Palaeogeography, Palaeoclimatology, Palaeoecology* 40: 31-66.
- Pivorunas, A., 1979. The feeding mechanisms of baleen whales. *American Scientist* 67: 432-440.

- Pledge, N. S., 1994. Cetacean fossils from the Lower Oligocene of South Australia. *Records of the South Australian Museum* 27: 117-123.
- Pledge, N. S. & Rothausen, K., 1977. *Metasqualodon harwoodi* (Sanger, 1881)-a redescription. *Records of the South Australian Museum* 17: 285-297.
- Pritchard, G. B., 1939. On the discovery of a fossil whale in the older Tertiaries of Torquay, Victoria. *Victorian Naturalist* 55: 151-159.
- Prothero, D. R. & Schoch, R. M., 2002. *Horns, Tusks, and Flippers: The Evolution of Hoofed Mammals*. The Johns Hopkins University Press, Baltimore, 311 pp.
- Rose, K. D., 2001. The ancestry of whales. *Science* 293: 2216-2217.
- Rothausen, K., 1968. Die systematische Stellung der europäischen Squalodontidae (Odontoceti, Mamm.). *Paläontologische Zeitschrift* 42: 83-104.
- Sanders, A. E. & Barnes, L. G., 2002. Paleontology of the Late Oligocene Ashley and Chandler Bridge Formations of South Carolina, 3: Eomysticetidae, a new family of primitive mysticetes (Mammalia: Cetacea); pp. 313-356 in R. J. Emry (ed.), *Cenozoic Mammals of Land and Sea: Tributes to the Career of Clayton E. Ray*. *Smithsonian Contributions to Paleobiology* 93.
- Sanger, E. B., 1881. On a molar tooth of Zeuglodon from the Tertiary beds on the Murray River near Wellington, S. A. *Proceedings of the Linnean Society of New South Wales* 5: 298-300.
- Scott, H. H., 1913. Notes on a fossil whale from Wynyard, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 1913: 167-172.
- Scott, H. H. & Lord, C., 1921. Studies in Tasmanian mammals, living and extinct. No. VI. Cetacean remains from the fossil beds at Wynyard. *Papers and Proceedings of the Royal Society of Tasmania* 1921: 180-181.
- Simpson, G. G., 1945. The principles of classification and a classification of mammals. *Bulletin of the American Museum of Natural History* 85: 1-350.
- Singleton, F. A., 1945. A catalogue of type and figured specimens of fossils in the Melbourne University Geology Department. *Proceedings of the Royal Society of Victoria* 56: 229-284.
- Thewissen, J. G. M. (editor), 1998. *The Emergence of Whales*. Plenum Press, New York, 477 pp.
- Thewissen, J. G. M. & Williams, E. M., 2002. The early radiations of Cetacea (Mammalia): evolutionary pattern and developmental correlations. *Annual Review of Ecology, Evolution, and Systematics* 33: 73-90.
- Thewissen, J. G. M., Williams, E. M., Roe, L. J. & Hussain, S. T., 2001. Skeletons of terrestrial cetaceans and the relationship of whales to artiodactyls. *Nature* 413: 277-281.
- Uhen, M. D., 1998. Middle to Late Eocene basilosaurines, and dorudontines; pp. 29-61 in J. G. M. Thewissen (ed.), *The Emergence of Whales*. Plenum Press, New York.
- Uhen, M. D., 2002. Basilosaurids; pp. 78-81 in W. F. Perrin, B. Wursig, and J. G. M. Thewissen (eds.), *Encyclopedia of Marine Mammals*. Academic Press, San Diego.
- Uhen, M. D. & Pyenson, N., 2002. Evolution of cetacean diversity. *Journal of Vertebrate Paleontology* 22(supplement to no. 3): 116A.
- Vickers-Rich, P. & Rich, T. H., 1993. *Wildlife of Gondwana*. Reed, Australia, 276 pp.
- Whitmore, F. C. Jr & Sanders, A. E., 1976 (1977). Review of the Oligocene Cetacea. *Systematic Zoology* 25: 304-320.
- Zimmer, C., 1998. *Fish With Fingers, Whales With Legs, and How Life Came Ashore but Then Went Back to Sea*. Touchstone, New York, 290 pp.

GLOBAL CHANGE: PAST, PRESENT AND FUTURE – A Palaeontologists View

The following is a summary of a talk given to the Royal Society of Victoria by **Professor Neil Archbold**, School of Ecology and Environment, Deakin University, Burwood Campus. The F.C.A.A. wishes to thank the Society for permission to reprint the summary contained in their March 2004 Newsletter.

Global change is a concept that we are all frequently exposed to, via the media, in the early 21st century. It is normally portrayed with a negative sense and often with a view that we should somehow stop the change (which is invariably attributed to human activity).

The Earth Sciences, and notably Palaeontology, demonstrate clearly that global change is normal in terms of the earth's history and is to be expected. Such changes can be slow (such as the movements in plate tectonics), instantaneous (such as impact events) or within days, months or a few years (such as volcanic events and the distribution of volcanic ash in the upper atmosphere).

Palaeontology, the science of the history and nature of past life, reveals the results of these random changes on the evolution of life. It reveals such details as rates of speciation, rates of extinction, palaeobiodiversity, palaeogeography and provincialism, palaeoclimatology and palaeoceanography. In short, it reveals global change and its impact on life.

Extinction is a regular and expected aspect of the history of life on Earth. Studies on modern life are far too often restricted to the study of so called 'crown' species (numbered in the tens of thousands). However, true biodiversity is to be found in the invertebrate world (millions) and estimates of the bacteria are mere guesswork. Estimates of total biodiversity of all species on earth since the beginning of the Cambrian period range up to 30 billion species with up to 30 million alive on earth today. These figures suggest that 99.9% of all species since the start of the Cambrian are extinct. The biggest extinction event in the earth's past of which we are aware is that which occurred at the boundary between the Permian and Triassic periods. That event happened relatively quickly – perhaps over 100,000 years. There is little

support for a major impact event as the cause of this extinction, the favoured explanation now considered to be but a combination of causes. The combination of massive basaltic volcanism in Siberia followed by the release of massive amounts of the greenhouse gas Methane from frozen methane hydrates in the oceans of the world is The net result has been estimated to have initiated the extinction of some 95% of all life on earth. A return to full biodiversity may have taken 5 million years although new evidence suggests that it could have been much shorter – perhaps only several hundreds of thousands of years. The old concepts of Lyell and Darwin of very slow and gradual change through time require modification. In recent years this has been advocated under the title of 'neo-catastrophism' but, in reality, is close to the true 'uniformitarianism' of James Hutton who advocated the notions of 'revolutions of the earth'.

The last 40,000 to 60,000 years of earth history has witnessed a staggering demise and extinction of crown species on earth. A dual role of climate change and spread of the human species appear to be clear causal features. The human effect may be through direct hunting, burning and so-called land management, and the introduction of feral species. The cause of the demise of the New Zealand Moa (some dozen species) is clearly direct hunting, that of the Mauritius Dodo is that of introduced feral species destroying nests and eggs (the Dodo was unpleasant for human consumption). This 'sixth extinction' is still occurring and evidence suggests at an increasing rate. The failure of the human species in dealing with global population growth, the increased development of agricultural monocultures and the extension of land use for agriculture, the use of land for urban expansion and the theoretical notions used to support economic growth, will ensure the continuation of the sixth extinction.

The question for humanity is 'Will the plague species survive or be a victim of the sixth extinction? Does it matter? Mankind is a part of nature. Most species survive some 250,000 to 5 million years on earth. Their survival is based on random events and consequential random successes. As stated by Stephen J. Gould, 'On geological scales, our planet will take care of itself and let time clear the impact of any human malfeasance.' Richard Leakey has written 'despite.....distortions of the biota that will remain, rebound will occur.' Nevertheless, I will still weep at the passing of a species of butterfly!

ARCHAEOPTERYX – A SINGULAR BIRD

Palaeontologists have finally decided that there is just one known species of *Archaeopteryx*, the controversial “missing link” between birds and dinosaurs.

Over the past 140 years, eight specimens of *Archaeopteryx*, seven skeletons and a single feather, have been discovered in 150 million year old limestones from the Solnhofen region of Bavaria. Debate has raged over the relationships between them. One fossil known as the Eichstätt specimen has been classified as *Archaeopteryx recurva*, another dubbed the Berlin specimen as *Archaeopteryx siemensii* and a third, called the Munich specimen, as *Archaeopteryx bavarica*. The rest have always been classified as *Archaeopteryx lithographica*.

Now Phil Senter and James Robins of Northern Illinois University have re-analysed the six *Archaeopteryx* skeletons using regression analysis on measurements of bones from the tail, shoulder, limb and hip to determine if differences between the specimens were due to different growth stages within the one species (*Journal of Vertebrate Paleontology*, vol. 23, p. 961). They have confirmed that all six skeletons are from *Archaeopteryx lithographica*, consigning the other three species to the taxonomic trash can. Their analysis excluded the feathered skeleton in the Bürgermeister Müller Museum – the Solnhofen specimen. In 2001, this was found not to be *Archaeopteryx* at all, but a new genus, *Wellnhoferia*.

Report from *New Scientist*, 17 April, 2004.

Details of specimens are given below with the author and date of assignment to the genus in brackets.

1. Feather, found near Solnhofen, 1860 [Meyer 1861]
2. London specimen, found near Langenltheim, 1861 [Owen 1863].
3. Berlin specimen, found near Blumenberg, 1877 [Dames 1884].
4. Maxburg specimen, found near Langenltheim, 1956? [Heller 1959]
5. Haarlem/Teyler specimen, found near Riedenburg, 1855.
Originally classified as *Pterodactylus crassipes* [Meyer 1857], it was eventually assigned to *Archaeopteryx* [Ostrom 1970]
6. Eichstätt specimen found near Workerszell, 1951 [Wellnhofer 1974].
7. Solnhofen specimen, found near Eichstätt, 1960's.
First identified as *Compsognathus* it was assigned to *Archaeopteryx* [Wellnhofer 1988] and subsequently to the new genus *Wellnhoferia* in 2001]
8. Solnhofen-Atlien-Verein specimen, found near Langenltheim, 1992 [Wellnhofer 1993]

MAGNIFICENT MIHIRUNGS: The Colossal Flightless Birds of the Australian Dreamtime

They stood three metres tall, weighed half a tonne and were the dominant species across the scrubby, fire-sensitive forests of ancient Australia. They were almost certainly the largest bird that ever walked the Earth – and its distant descendants are spread across the wetlands of Kakadu to this day. Yet the Mihirung, the prehistoric giant goose of the central deserts, has remained an obscure scientific anomaly, a curio. Until now, almost completely unknown.

That may be about to change with the publication of *Magnificent Mihirungs – The Colossal Flightless Birds of the Australian Dreamtime* by Peter Murray and Patricia Vickers-Rich, a book almost as remarkable for its cover art by Victorian artist Peter Trusler, as for its tightly argued contents.

Over millions of years, Australia's unique biodiversity has produced a large cabinet of curiosities. Among the weirder members of this group were the Mihirungs, members of the now extinct family of Dromornithidae. Made up of several genera of flightless birds – among them one of the very largest birds that ever lived – the dromornithids ranged from 60 kilogram beasts, 1.5 metres tall to giants twice that size, weighing nearly half a tonne. They were by orders of magnitude, the largest "geese" that ever lived. One species was comparable in size to the Elephant bird of Madagascar and the Giant Moa of New Zealand. Although bones of this type were first spotted by Sir Thomas Mitchell in the 1830s, this book is the first major study of this unique and highly diverse group. It aims to present as complete a synthesis as possible of current information about this fascinating family of birds.

Peter Murray, the fossil detective whose sleuthing pieced together the big goose's true genealogical place is the Curator of Palaeontology at the Museum of Central Australia in Alice Springs.

Patricia Vickers-Rich is Professor of Palaeontology, School of Geosciences, Monash University, Clayton, Victoria.

Magnificent Mihirungs by Peter F. Murray and Patricia Vickers-Rich.
Published by **Indiana University Press**, April 2004. Hardback 416pp.
ISBN 0-253-34282-1. RRP AU\$125.00 (US\$75.00)